



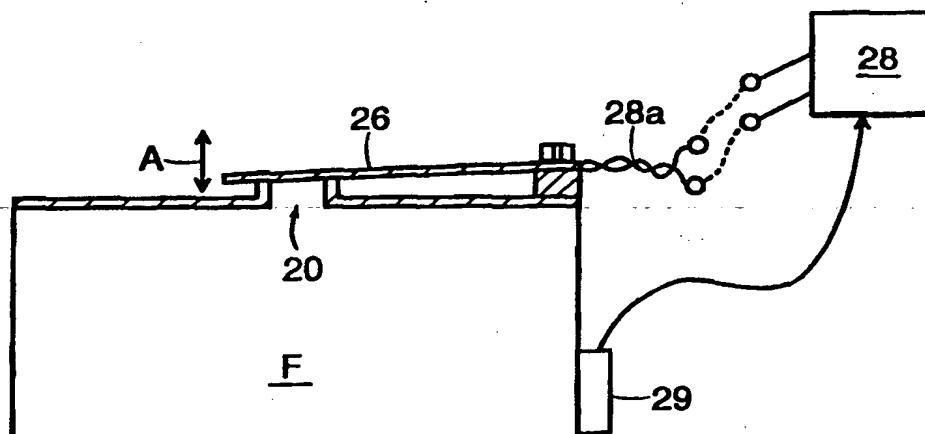
INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification ⁶ : F16F 9/46, B60G 17/08, B62K 25/04		A1	(11) International Publication Number: WO 99/04182
			(43) International Publication Date: 28 January 1999 (28.01.99)
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(22) International Filing Date: 10 July 1998 (10.07.98)			
(30) Priority Data: 60/052,418 14 July 1997 (14.07.97) US		(81) Designated States: BR, CA, JP, KR, MX, US, European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE).	
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(54) Title: ADAPTIVE DAMPER

(57) Abstract

A valve regulates fluid displacement in a damper assembly, for example, displacement of hydraulic fluid in a sealed shock absorber. The valve is placed between a portion of fluid at one pressure and regulates the passage of fluid through an aperture or passage to a portion of fluid at a lower pressure by a blocking member which moves to obstruct the aperture in accordance with a desired level of damping. The blocking member includes an electroactive device, such as a bimorph actuator formed of ferroelectric material. In one embodiment, the blocking member covers the aperture and is flexibly displaced by passage of pressurized fluid through the aperture. A controller receives position signals, and actuates the bimorph toward or away from the aperture, augmenting or decreasing its closing bias to affect both the threshold flow initiation pressure and the rate of flow once the passage opens. Preferably the blocking member is a flexible piezoelectric assembly, which moves across a gap to provide a varying obstruction in the near field of fluid flow as the fluid moves through the passage. A position sensor connected to the controller senses piston position, and the controller operates to energize the bender and to obstruct the opening or to further restrict flow if the piston position or its velocity is determined to lie above certain thresholds. This extends the useful range of the damper and may allow optimal stroke of the damper during all conditions of use, enhancing comfort while preventing bottoming out. Various pinned, sliding or cantilevered constructions of electroactive elements are adapted to different passage geometries and release characteristics. The valve assembly may be implemented in a plenum that attaches between chambers of a fluid housing. In a preferred embodiment, the device is powered by a battery or rechargeable cell. The controller monitors piston motion, and when it detects a static or parked condition switches to a sleep mode to reduce power consumption.



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ADAPTIVE DAMPER

Background

The present invention relates to a fluid valve, and more particularly to a valve having different, or variable, settings for affecting flow of a fluid. In a preferred embodiment it relates to a fluid valve for damping a hydraulic assembly.

A number of devices in the prior art employ hydraulic or fluidic dampers or dashpots to
5 smooth out mechanical motion or jitter. Vehicle shock absorbers are one example of such devices, and substantially similar devices are used for office chairs, door closers, and other applications. In several of these applications the device is subject to asymmetrical impulse actuations, or operates in a range of motion about a set point offset from its center. For example, a vehicle shock absorber may be subject to upward impulses in which energy is delivered in larger
10 amounts, or during shorter time intervals, than the gravity- and spring-driven downward return movements. Furthermore, the expected disturbances may cover a wide range of energies and occur at unpredictable intervals and times.

Conceptually, a vehicle suspension generally includes a spring and a fluid damper. The spring elastically stores and returns the energy of up-and-down motion of a mechanical assembly,
15 such as the hub driving the wheel, to smooth the sharp impacts caused by running over irregularities in the roadway and restore the suspension to a neutral position, while the damper dissipates a portion of the energy in each stroke or cycle to prevent resonant oscillations from arising. Energy dissipation is achieved by introducing frictional losses. This may be done by arranging that a piston connected to the suspension displaces hydraulic fluid through a flow
20 impediment, e.g., one or more small orifices that introduce turbulence, drag, viscous shear or other lossy events in the fluid, which may for example be a liquid or a high pressure gas.

Practical implementation of such a mechanical damper entails considerations of the expected frequency and shape of displacement impulses, vehicle mass and speed, the desired range of motion of the suspension, and the required strength and allowable weight of the damper
25 assembly. For automobiles, suitable shock absorbers are achieved with piston-type assemblies located at each wheel, and each weighing two to ten kilograms, with a piston travel of about five

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to thirty centimeters. Smaller assemblies may be used on mechanisms such as steering arms or tailgate assemblies, while even larger ones may be necessary to accommodate heavy loads or travel over rough roadway surfaces.

When an assembly of this type is to be used for a mountain bicycle, weight is a primary consideration since the total vehicle weight must be pedaled by the user. Furthermore, the vehicle handling is strongly affected by the characteristics of the damper. The front suspension, e.g. a telescoping fork, is the steering mechanism, and impacts on the rear wheel may pass fairly directly to the seat, so both the comfort and actual steering aspects of handling are affected.

One known bicycle shock absorber employs a piston that displaces fluid within a hydraulically full and sealed cylinder. The piston has a number of passages extending between one side and the other, and each passage has a flexible washer fastened over one end to act as a one-way flap valve allowing flow in only the forward, or only the reverse direction. The number and sizes of these passages are configured to resist fluid displacement and thus control movement of the piston when the bicycle is subjected to changing terrain and impact. This construction is structurally strong and mechanically robust. However, because of the extreme range of conditions which a bicycle may experience, these shocks cannot operate optimally under some combinations of diverse conditions. When the passages are sized to resist flow of hydraulic fluid only weakly, a smoother or "soft" ride is obtained, but a large force will cause the shock to quickly "bottom out" and become ineffective. On the other hand, if the passages are configured to inhibit flow so much that the shock absorber never bottoms out under conditions of energetic impact, then the shock absorber provides a "hard" ride, greatly reducing comfort. It is generally desirable to have a stiff suspension during pedaling, so that the energy of pedaling is not lost into the suspension. However, between periods of pedaling, when there are moderate impacts, a softer ride would be advantageous. However, the vast majority of bicycles which currently have any type of shock absorbers only permit a fixed adjustment of their properties.

Accordingly, it would be advantageous to provide a flow valve having different characteristics suitable for controlling a range of expected flows occurring over a wide range of driving conditions.

It would be further advantageous to provide a flow valve with variable flow control or regulation characteristics which change to match existing conditions.

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Summary of the Invention

One or more of these ends are achieved in accordance with the present invention by providing a valve to regulate fluid displacement, for example the displacement of hydraulic fluid by a piston in a sealed shock absorber, wherein the valve is placed between a portion of the fluid at one pressure and controls fluid flow as the fluid is driven along a passage to a portion of fluid at a lower pressure. An aperture constitutes or communicates with the passage, and a controller moves a blocking member to obstruct the aperture in accordance with a sensed use parameter, e.g., a function of piston displacement to dynamically or adaptively change the damping. An electroactive device, such as an actuator formed of ferroelectric material, preferably positions the blocking member.

In one embodiment, the blocking member is a bimorph which covers the aperture. The bimorph is deflected by passage of fluid through the aperture, and the controller provides an electrical activation signal to drive the bimorph toward or away from the aperture, augmenting or decreasing its closing bias. This affects both the threshold flow initiation pressure, and also the degree of flow permitted once the passage is opened. Actuation of the member bends it into the stream to affect flow. Preferably the blocking member is a flexible piezoelectric assembly, which moves across a gap to provide a varying obstruction in the fluid flow as the fluid moves through the passage.

In a presently preferred embodiment, the damper assembly is employed in a cycle shock absorber, and it includes a position sensor connected to sense piston position. The controller operates to energize the bender and to obstruct the opening or to further change flow if the piston position and/or its velocity is determined to lie in certain threshold ranges. This extends the useful range of the damper and allows optimal stroke of the damper during varied conditions of use, enhancing comfort while preventing bottoming out and unnecessary loss of rider energy. Other passages which may have fixed or conventional one-way valves in each direction, are also provided to tailor the general damping characteristics of the damper. The controller may be switched between three states to soften the response provided by the fixed valves, to stiffen that response, or to provide both actions as appropriate based on the sensed conditions. In its adaptive or dynamic state, the controller may include several different control programs that are user-selected by a panel switch to optimize comfort, energy/speed or other characteristic or combination of characteristics. Alternatively, different programs may be selected automatically

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based on the form of the sensed signals. Preferably the blocking assembly is driven from a battery or rechargeable cell power source, and the controller monitors the sensor signal and shuts down when sensor conditions indicate that the cycle is idle.

Brief Description of the Drawings

5 These and other features of the invention will be understood from the description herein, together with illustrative drawings, wherein:

FIGURE 1 shows a partly schematic cross-sectional view of a first embodiment of the invention;

FIGURE 1A shows a similar view of a second embodiment;

10 FIGURE 1B shows prior art fixed damper elements which may be used in the embodiment of FIGURE 1A;

FIGURES 2 and 2A show exploded views of a third embodiment of the present invention implemented in a shock absorber;

FIGURES 3 and 3A illustrate details of a fourth embodiment of the invention;

15 FIGURES 4 and 4A illustrate details of a further embodiment of the invention;

FIGURES 5A-5I illustrate details of further embodiments;

FIGURE 6 is a control table used in a preferred embodiment; and

FIGURE 6A is a flow chart of controller operation.

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Detailed Description

FIGURE 1 shows a basic embodiment of the invention wherein a system or device includes a body of fluid F at a first pressure that is driven through a passage 20 and controlled by a deformable flow restrictor 26 responsive to electrical control signals from a controller 28, which, in turn, receives sensing signals from a sensor 29. The sensor 29 may, for example, detect the position of a assembly, the pressure or flow of the fluid, or an impact, load or disturbance to which the device is responding. In this embodiment, the deformable flow restrictor 26 is a plate-like member, cantilevered across the passage 20 to block the opening with a varying degree of obstruction. For example, the plate 26 may be an encapsulated piezoelectric sheet, e.g., a two-layer piezo bender made in accordance with the teachings of commonly-owned published International Patent application WO95/20827, and clamped over the passage in the manner of a valve as described, for example, in commonly owned U.S. patent application 08/760,607 filed December 4, 1996. Each of those documents is incorporated herein by reference for their descriptions of methods of fabricating such piezoelectric plate devices. As relevant here, the plate 26 may be a bimorph assembly mounted to exert a downward (as illustrated) force over the passage 20, for example in the range of 0.1 to 1.0 pounds, and to be pushed open and deflected along the direction of arrow "A" by the fluid pressure. The controller 28 applies a voltage across one or the other elements of the assembly to cause it to bend toward or away from the opening and to augment or diminish the closing bias of the plate over the passage. For example a voltage of fifty to two hundred volts or more may be applied to actuate the assembly.

FIGURE 1A illustrates generally these basic elements of the flow controller in a damper in accordance with the present invention. As shown schematically in cross section, a piston 2 is displaced within a housing H filled with fluid F, dividing it into two chambers C₁ and C₂. The piston seals against walls of the chambers, and the housing is hydraulically full, so movement of the piston in the direction of one chamber forces fluid to the other chamber, for which purpose a fluid return assembly 10 including a return passage 12 is provided. Thus motion of the piston along the direction of the axis of its shaft 4 shifts the relative sizes of the chambers C₁, C₂ and moves fluid therebetween through the assembly 10. More generally, the displacing body or source of fluid-driving pressure may reside entirely separate from the assembly 10, and be connected by a conduit. For the illustrated structure, in a practical implementation, the other end of the piston shaft may connect, as is well understood, to the structure or assembly which is to be

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damped, for example to a wheel axle or front fork of a bicycle. As shown schematically, fluid communication between the two sides of the piston is effected by passage indicated generally by 12, which communicates with a space 12a enclosing a bypass opening 20 leading from chamber C1, via a blocking member 26 positioned over the opening 20. Fluid pressure drives the member 26 upward, opening the aperture 20. The resistance to flow presented by the aperture 20, blocking member 26, and passage 12, together, serves to limit the rate of fluid displacement, hence the rate and the amount which piston 2 may travel, when the piston is subjected to an impulse. Furthermore, as illustrated, the blocking member 26 is suspended over aperture 20, so that when the piston 2 moves downward to increase fluid pressure in chamber C2, force on member 26 drives it closed, in the manner of a reed or flap. The valve therefore operates unidirectionally to allow flow only from C1 to C2.

Other mechanisms known in the art and not illustrated in FIGURE 1 may be provided to allow damped flow from C2 to C1, and further mechanisms of reverse orientation to provide additional damped flow from C1 to C2, so that hydraulic assembly operates as a basic bidirectional damping assembly. Such other mechanisms may include fixed one-way openings running directly through the piston head with valved endings to allow flow in one or both directions, as is known. Such fixed, one-way flow restriction passages are shown in a piston 2' in FIGURE 1B. One passage *u* opens directly through the piston head and has a flexible washer *w* positioned beneath it to flex open when upward pressure on the piston raises the pressure in the upper chamber and drives fluid downwardly. A second, illustratively larger, through passage *d* has a flexible washer over its top end, and provides a generally softer restriction or larger flow allowing damped flow during downward motion of the piston. Additional prior art fixed damping passages of this type (not illustrated) may be provided in the piston 2 in the embodiment of FIGURE 1A.

Returning to FIGURE 1A, the blocking member 26 is suspended with a fixed mounting portion 26a fastened to the housing, and a free end 26b positioned to cover the aperture 20. Control leads 28a extend from the blocking member to a control unit, not shown, which provides electrical control signals to regulate the member 26 and control its damping characteristics as described in more detail below. In this embodiment, the member 26 is a cantilevered sheet, such as a piezobender or other electrically actuated bimorph, and actuation of the bimorph increases or decreases the force with which it biases the aperture 20 closed, and correspondingly decreases or

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increases its displacement, respectively, away from the opening when it is driven open under the influence of fluid pressure exiting the aperture. A sensor 29a illustratively a magnetoresistive sensor, is mounted in the housing near the top and illustratively provides a signal to the controller indicating the current travel or proximity of the piston. Other sensors, such as a pressure sensor
5 may also be provided. As noted above, in the prior art piston construction of FIGURE 1B, the piston 2' moves bidirectionally within a cylindrical housing to displace fluid, and a plurality of passages are formed directly through the piston head to damp its displacement. Generally a first set of passages includes several of the passages u open to the upper face of the piston, which have their lower ends obstructed by a flexible washer or a flap w , so that when pressure above the
10 piston exceeds the pressure below by a certain amount, fluid may deflect the washer and pass through the passages. A second set includes several of the apertures denoted d , which are illustratively of larger size or may have a more easily displaced flex flap or washer w , to allow flow in the reverse direction when the piston is pushed in the opposite sense (downwardly) by the return spring. Advantageously, the damper of FIGURE 1A, or of FIGURE 2 discussed below,
15 may incorporate a piston of this prior art construction. In that case, the apertures may be made smaller or more obstructed than usual, to provide a generally harder or stiffer ride than the prior art general-purpose damper. The piezo-controlled aperture 20 (FIGURE 1A) then functions as an additional flow path, or a bypass valve, which allows the shock absorber to have significantly more extended range, and either an automated or user-set electric selection of its range or
20 characteristics.

In FIGURE 1A, the housing H and piston 2 are shown in a generally vertical orientation, resulting in upper and lower chambers, and the return or bypass assembly is located lateral to the principal chambers. Since the housing and bypass are hydraulically full, actual physical orientation of the assembly is substantially irrelevant to its structure and operation, and it will be understood
25 that the damping assembly may reside horizontally, or obliquely, such as, for example, when connected between cross-members of an articulated frame or suspension. However, to provide a uniform vocabulary for referring to the opposed chambers, these will be referred to simply as "upper" and "lower" chambers, and these terms will be used to describe the corresponding motions, and the portions of the housing and passages from the chambers. However despite the
30 non-directionality of the damper in this sense, one asymmetry that is generally present in the preferred applications, is that the valve assembly preferably operates to affect the flow of

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displaced fluid in one direction, and may be operated to further restrict flow when the piston displacement is driven toward its end of travel in the housing. This condition especially arises, or is most challenging to manage in the case of a vehicle shock absorber, along the direction experiencing roadway impact impulses, rather than the direction of spring return motion that generally occurs after some damping of the initial impulse, and is subjected to lower maximum forces exerted over potentially longer time intervals. However, even in that context, as noted above the invention contemplates that the bypass assembly of the invention may include a further valve mechanism, or more than one such mechanism, to dampen either one or both directions of displacement. Such operation will be more readily understood from the detailed discussion below.

FIGURE 2 shows an exploded perspective view of a damper valve 100 of the present invention incorporated in a bicycle shock absorber. The valve includes a controlled return assembly 110 which is mounted to a fluid displacing assembly 140. The fluid displacing assembly has the overall structure of a bidirectionally movable hydraulic piston/cylinder assembly, including a piston 142 mounted on a shaft 144 and reciprocable within a fluid housing 145. An end cap 146 secures the piston in the housing 145 and seals about the shaft, and the piston itself divides the housing into upper and lower chambers. A lateral surface region 110a of the housing 145 is configured for sealing attachment to the valve 110, and has a surface 111 with passages 111a, 111b opening to the interior of the fluid housing. The passages 111a extend from the surface 111 to the interior of the housing 145 above the piston 142, while the passages 111b enter at a level generally lower than the normal position of the piston. Thus fluid will be driven from the cylinder through the passages 111a or 111b depending on whether the piston 142 moves upward or downward.

In this embodiment, the valve assembly 110 sealingly fits over the surface 111 and is clamped down with a gasket 110b to maintain the assembly sealed. An electrical controller 150 connects to the valve 110 and provides control signals to affect its operation, described further below. Within the assembly 110, shown in greater detail in FIGURE 2A, an aperture plate 130 separates the passages 111a extending to the first chamber from those extending to the second chamber, and a piezoelectric member varies flow characteristics through the aperture to control the damping achieved by the assembly.

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As shown in FIGURE 2A, the valve assembly 110 includes a lower aperture plate 130 having an aperture 132 therein and the blocking member 134 having a flexible conductor or lead in 134a, such as a ribbon connector, extending therefrom to the controller 140 to electrically actuate the member 134 and control its blocking force or position over the aperture 132. The lower aperture plate 130 has an area smaller than the total surface 111, and is fitted against that surface with a gasket 110b (FIGURE 2) so as to entirely cover the first set of passages 111a without covering the passages 111b. Fluid exiting the passages 111a must therefore pass through the aperture 132 to reach the passages 111b. Above the blocking member 134, which is shown as a cantilevered piezoelectric bending sheet, a cover plate 136 encloses the second side of the aperture plate, and assures that fluid exiting aperture 132 is forced through passages 111b. A seal ring 136a fits around the conductor ribbon 134a of the piezoelectric actuating member, to provide a seal where the conductor exits the housing of the valve assembly 110, and a clamp plate 136b compresses the seal over the electrical passage. The flexible conductor is attached to the controller 150 (FIGURE 2). Thus, the valve forms a bolt-on assembly over a shock absorber to provide electrically controlled and variable damping of the fluid flow between chambers of the shock absorber. It will be understood that since the blocking member 134 is suspended on the outflow side of aperture 132, it will allow passage of high pressure fluid from the upper to the lower chamber, but will be urged more tightly in contact with the aperture by the reverse pressure gradient and therefore block return flow from the lower to the upper chamber. Thus, it serves to variably damp motion of the shock absorber in one direction, allowing a stiffer or softer motion. Such actuation alone would, of course, result in the shock absorber moving in one direction and locking up at the end of its travel. Thus, it is understood that further passages for return of fluid are provided.

The return passages may be of similar operation, or may be fixed passages of conventional type, in which case only the damping in one direction is electrically varied. In the prior art as noted above, communication between chambers is accomplished by having two sets of one-way apertures, for example, flap-covered valves or flow restrictor passages in the piston head itself as shown in FIGURE 1B. Each set of apertures allows a restricted damped fluid flow from one side to the other, and the number and areas of the apertures, as well as the restrictions provided by the flap covers, are selected to assure that the energy required to move the piston in each of the two directions is appropriate for the desired level of damping. These prior art damping passages each

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have fixed flow characteristics set by their mechanical structures. By contrast, the blocking member 134 and aperture 132 provide an electrically varied damping bypass, whose characteristics are changed by the controller by application of different electrical signals. The bypass may thus soften the fixed stiffness provided by the prior art construction. The exact size or degree of restriction applied to the aperture 132 will vary depending on measured or intended conditions, and is controlled by the controller 150.

The invention also contemplates that both the upward- and the downward- return flow passages may be actively controlled by electrical signals. In that case, both the impact-driven direction and the spring return motions may be electrically controlled to enhance handling. However, the principles of operation are the same, so for illustration herein only one-direction control will be discussed in detail.

In general, the controller 150 may include user-selected modes which operate as a simple electrical switch to apply one of several, illustratively three different control signals across the control member 110 to switch it between different biased positions over the aperture. These may include a zero-voltage or simple mechanically-biased state, and two states to drive one or the other piezo element of the bimorph bender to enhance or decrease the blocking force. In accordance with this aspect of the invention, the blocking member 134 is preferably mechanically mounted to bear against the aperture 132 in its neutral or electrically unactuated state, so that it serves as a plate cantilevered over the opening. The member 134 is a preferably a piezoelectric bimorph constructed as shown, for example, in commonly-owned U.S. patent application serial No. 08/188,145 filed on September 10, 1996, or is otherwise built to achieve a stiff member that develops a high actuation force in a short time, and to reside in the fluid and resist cracking and electrode failure. Thus, when one control signal, illustratively between about ten and several hundred volts or more, is applied to the blocking member 134, it deflects and bends toward the aperture, increasing its bias force. When the controller applies a different signal, the blocking member 134 moves away or is urged in the opposite sense, decreasing its bias force and allowing the passage 132 to open more easily, at lower pressures, and to open wider, thus permitting greater amounts of fluid through per unit time. The aperture may have a relatively small area, between several square millimeters and about one square centimeter, so that despite the relatively high pressures which may arise, the piezo actuation forces are sufficient to significantly resist opening of the valve and substantially alter the flow through the aperture once it has opened. This

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is because when the stiff but flexible piezo plate is pushed aside by the fluid pressure, the blocking member moves in the near field of fluid flow to still exert frictional drag on the moving fluid. At the relatively small gaps involved, typically under a millimeter or two and with flow interacting with the larger areas of the actuator sheet, fluid control forces are significant. Furthermore, the closing force is substantial, typically between about 0.1 and 1.0 pounds.

Preferably, the controller is powered by a simple and light weight dry cell battery, such as a nine volt battery of small size, or by a similar small rechargeable cell. Voltage doubler circuits of solid state construction are preferably provided, and may be arranged in series as a charge ladder to increase the voltage to suitably high level, so that the piezo elements can be quickly switched between charge states and actuated in a relatively small time interval. For piezoelectric elements about ten to sixty mils thick, an actuation voltage of about two hundred to six hundred volts is used, and the elements charge quickly to provide a response time that is shorter than the natural frequency of the vehicle suspension.

As noted above, the controller also provides a non-fixed control that may include switched combinations of the basic actuation signals. For this purpose it receives a signal upon which it bases its control regimen from a sensor such as the position sensor 129 described above which detects the proximity of the piston to the top of the cylinder. Such a position sensor 129 is shown in FIGURE 2. Position sensing may be implemented in one embodiment by forming the housing of non-magnetic material and providing ferritic or magnetic material in the piston head, and by providing the sensor 129 as a magneto-resistive element located in the housing to detect in a continuous manner the distance to the piston head. In accordance with this aspect of the invention, the controller monitors the signal received from the position sensor, and determines the position of the piston in the chamber. In a presently preferred embodiment, the position sensor resolves piston position within several millimeters, and the position signal is polled at a frequency above several hundred Hz. Successive signals are differenced to provide the current piston velocity and direction of piston movement. The two parameters are then used as indices to a look-up table to determine a control signal for the blocking member.

As noted above, in general a hard (stiff) or soft ride may be provided by actuating the member 26 with driving signals towards or away from the opening 20. The controller preferably monitors piston position to determine when substantial movement occurs. Normally a stiff (blocked) position is used for pedaling, switching to a softer damping position for road impacts.

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If the impacts are particularly energetic, the controller may restrict flow in anticipation of the piston travel, while as piston position approaches the end-of-travel, the controller may again switch to further obstruct the opening. Thus, if the piston continues to move energetically upward, the controller increases the actuating signals to increase the blocking force applied by the member 134. This further restricts flow through the aperture and assures that the piston does not bottom out against the top of the chamber. However, when the piston is moving upward but has not approached the top of the chamber, the controller may apply a lesser signal, or no signal at all, or a soft damping signal, to allow less obstructed flow through the bypass and produce a relatively soft damping effect and smoother ride during the early stages of piston travel. The shock absorber therefore performs with greater comfort than it would if the suspension were fixedly made stiff enough for maximum pedaling efficiency, or soft enough for general purpose damping. In particular it may assure the piston does not mechanically contact the top or bottom of the cylinder yet provide a generally softer ride. FIGURE 6 illustrates one implementation of this control strategy.

As shown in that FIGURE, the piston position signal is normalized to yield the position as a relative position between zero and one hundred percent of its travel, and this measurement data is plotted along the Y-axis or abscissa, while the current piston velocity is computed from this signal and scaled and plotted along the X-axis over the piston speed range of zero to one hundred inches per second. The position/velocity space is then divided into distinct regions in which the control signal applied to the piezo blocking element is biased toward, neutral biased, or biased away from the opening. These three control states correspond to hard, medium and soft damping characteristics. During operation in the automatic control mode the controller determines piston position p and velocity v , then consults a look-up table to determine the control signal, corresponding to the region surrounding the point (p,v) , which is to be applied to the blocking member.

The substance of the look up table is shown in FIGURE 6. Briefly, the control regimen may be logically stated by the following rules:

1. If the piston position p is less than 25% of the total displacement, the control signal is set to MEDIUM; as noted above the MEDIUM setting may correspond to applying no actuation signal, so the mechanical bias and stiffness of the blocking member determine the flow restriction characteristics

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2. If p is between 25 and 60%, or if p is between 60% and 70% at a velocity under 30 ips, then the control signal is set = SOFT

3. If p is between 60% and 70% at a velocity between 30 and 60 ips, the control signal is set = MEDIUM

4. If p is between 70% and 100% at a velocity under 30ips, the control signal is set = SOFT if the previous control signal was soft, and otherwise it is set = MEDIUM

5. Otherwise, the control signal is set = HARD. This last set of conditions corresponds to the (p,v) region of relatively fast piston velocity occurring in the far range of piston travel.

Intuitively, operation of the controller may be understood by considering the curves b_1 , b_2 shown schematically passing through the (p,v) coordinate space. Each curve b_i represents a set of piston coordinates as the piston responds to a bump. The curve b_1 shows the response to a relatively soft bump, corresponding to low cycle speed or a small size trail irregularity or rise, in which the piston velocity remains below 30 ips and the velocity is well controlled by soft damping so that it diminishes before the piston has traveled much beyond its mid range of travel. The curve b_2 represents a harder or more energetic motion, in which velocity increases relatively sharply and hard damping is necessary in the second half of the travel range to reduce the velocity. In each case, the piston velocity is returned to zero before 100% piston travel can be reached, so the piston does not "bottom out", i.e., crash into the top of the housing at a high velocity.

FIGURE 6A is a flow chart to show another control mechanism which the controller simultaneously applies to the sensed position signals. As shown therein, once the automatic control mode is actuated, the controller monitors the (p,v) values of the piston and looks up its control parameter to apply to the blocking member. If the detected piston value is below a certain threshold value ϵ (for example below a 1% displacement, or below 1 ips velocity) which indicates that the bicycle might actually be parked or not in use, the control microprocessor determines whether this inactive state has persisted for some time, illustratively five or ten seconds. If so, it enters a "sleep mode", disconnecting the battery power from its circuitry to conserve energy. In this case, the unpowered blocking member sits in its "medium" state until the user again presses the ON button to re-activate the controller and initiate the sensor polling, control signal look-up and adaptive blocking regimen to actively damp piston motion. In one prototype embodiment, the controller entered sleep mode when the piston displacement remained below 1% for at least

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seventeen minutes rather than several seconds. In alternative embodiments, the sleep mode may operate by selectively de-energizing the more power-intensive portions of the circuitry of the controller, such as the piezo driver and position-detecting circuitry.

While the above operation assumes measurement of one parameter (position) and
5 computation of another (speed), the invention also contemplates constructions wherein the controller incorporates more complex detection mechanisms or software signal processing to determine piston speed, for example by computing the difference between an ensemble of successive positions, or wherein the controller calculates the piston acceleration and uses a more complex 3-coordinate look-up table to anticipate the severity of an impact before the piston has
10 traveled too far, and to respond by increasing the damping earlier during strong or abrupt piston strokes. Other sensors, such as a piston shaft encoder, or a pressure sensor may alternatively be provided from which the controller determines the appropriate direction and magnitude of its blocking member control signal. In general these additional velocity- or acceleration-indicating signals are derived by a simple processor-implemented differencing of the basic position or
15 pressure values sensed by a sensor.

The invention further contemplates constructions wherein the passages between upper and lower chambers run through the piston head, and piezoelectric control members are mounted on the piston itself to variably restrict these flow passages. FIGURES 3A, 3B and 4A, 4B illustrate such embodiments. In each of these configurations, a piston has multiple passages extending
20 through its head, and the electroactive flow restrictor 26 is mounted, preferably concentrically on the shaft, and is deformed or actuated to vary the damping achieved by the passages. Electrical leads may be run through the shaft, or otherwise provided for energizing the piezo portions PZ. A support plate 26a may be used to limit travel and further define the aperture restriction geometry and bending stiffness of the blocking members. The passages need not be cylindrical holes, but
25 may be openings or passages of any shape adapted to be effectively obstructed by an electroactive sheet elements. Such shapes may include, for example, a slot-like passage of rectangular cross section, in which a bimorph sheet or actuator resides, to restrict the narrow flow passage and deforms to bend into the flow stream and obstruct the passage. Other passages or openings, and other actuator shapes are also contemplated, and may be adapted to the particular range of
30 pressures and rates of flow which are expected in use.

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Thus, rather than a cantilevered sheet or plate having an end extending over a opening, a number of mechanical systems including pinned-pinned, clamped-pinned, clamped-sliding and other actuator mountings are envisaged for effectively obstructing flow through a passage, or through an orifice or aperture. Several such configurations are shown in FIGURES 5A-5I.

5 These FIGURES illustrate piezobenders in various mechanical configurations adapted for the damper of the present invention. The embodiment of FIGURE 5A represents a cantilevered piezobender as shown in the earlier FIGURES, while FIGURE 5B shows an embodiment pinned at both ends. Such a pinned-pinned configuration achieves a higher blocking force at the nozzle or aperture. A pre-curved blocking element (FIGURE 5E) may be employed to provide greater
10 displacement, or faster overall response, while FIGURES 5F and 5G show obstructers in the flow passage itself. The electroactive element need not itself constitute the obstruction, but may instead be positioned to move an obstructing body 27, as shown in FIGURE 5I.

In addition to their specific actuation characteristics, one of these mechanical configurations may be selected based on other considerations to fit a particular housing shape or
15 mechanical structure in which the flow damper is to be housed.

This completes the description of the basic embodiments and configurations of the present invention. The invention being thus disclosed and described, variations and modifications thereof will occur to those skilled in the art and all such variations and modifications are considered to be within the scope of the invention as defined in the claims appended hereto.

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Claims:

- 1) A damper for a hydraulic system of the type having a movable displacing member that acts on a fluid assembly such that movement of the displacing member creates a pressure to induce flow in a passage in accordance with force on the movable displacing member, wherein the damper comprises a flexible electroactive element positioned to control flow in the passage and being configured with electrodes such that application of a control signal to the electrodes deforms said electroactive element to control said flow and regulate damping of the hydraulic system, and also includes a sensor for sensing a displacing disturbance, and a controller responsive to the sensor for determining the control signal.
- 2) A damper according to claim 1, wherein said sensor senses pressure in said passage.
- 3) A damper according to claim 1, wherein said sensor determines a function of position of said movable displacing member.
- 4) A damper according to claim 3, further including a battery power source and a voltage multiplier for developing said electrical control signal.
- 5) A damper according to claim 3, wherein the controller includes a sleep mode to reduce power use during quiescent periods.
- 6) A damper according to claim 1, wherein the movable displacing member is a push-pull piston assembly of a vehicle suspension, and the damper includes a plenum attached in fluid communication between opposite sides of the piston assembly, said passage being formed in the plenum, and wherein the flexible electroactive element is mounted on the plenum to variably obstruct flow through the plenum.
- 7) A damper according to claim 6, wherein the damper is a bicycle or motorcycle suspension damper.
- 8) A damper according to claim 6, wherein the electroactive element includes a piezoelectric bimorph having a free edge extending over the passage.
- 9) A damper according to claim 1, wherein said flexible electroactive element constitutes a blocking member having a bias force or position that varies in accordance with said control signal.

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1 10) A damper according to claim 1, wherein the flexible electroactive element is configured to
2 be displaced by pressure of fluid at said passage.

1 11) A damper according to claim 10, wherein said electrical charge effectively varies
2 maximum displacement of a blocking member occurring under influence of fluid flow through the
3 aperture to regulate shape of a damping curve.

1 12) A damper according to claim 1, wherein the controller activates the electroactive element
2 to increase stiffness of the hydraulic system and prevent bottoming-out.

1 13) A damper according to claim 1, wherein the controller switches said control signal
2 between different signal levels effective to provide sufficient damping to prevent bottoming out.

1 14) A damper in accordance with claim 1, wherein the passage and electroactive element are
2 effective to variably block and therefore change flow along said passage in a first direction, while
3 substantially completely blocking flow in a reverse direction.

1 15) A damper according to claim 1, wherein the passage is located in a piston and said
2 electroactive element variably obstructs flow through the piston.

1 16) A damper according to claim 1, wherein the hydraulic system is a bicycle suspension and
2 the controller applies a control signal at a rate faster than natural frequency of the suspension.

1 17) A damper according to claim 9, wherein the bias force or position control is proportional
2 to a sensed disturbance condition.

1 18) A damper for a hydraulic system of the type comprising a movable displacing member in a
2 fluid filled assembly such that movement of the displacing member forces fluid from a first fluid
3 filled chamber to a second fluid filled chamber or back as the member moves forward or back,
4 respectively, in the assembly, wherein the first and second chambers communicate via an aperture,
5 and the damper comprises

6 a sensor for sensing a function of piston position

7 an electrically actuated blocking member over the aperture, and

8 a controller responsive to the sensor for selectively energizing the blocking

9 member to provide or restrict flow through the aperture so as to achieve smoothing and

10 comfort while effectively preventing bottoming-out of the displacing member.

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- 1 19) A bicycle shock absorber comprising
2 a hydraulic piston assembly which divides a closed fluid body into upper
3 and lower chambers
4 an aperture forming a flow passage between said upper and lower
5 chambers
6 a flexible piezoelectric member positioned to deform by fluid pressure and
7 move to control flow through the passage, and
8 means for applying electrical energy to the piezoelectric member in
9 accordance with a detected disturbance in an amount effective to prevent
10 bottoming-out of the piston assembly.
- 1 20) The bicycle shock absorber of claim 18, further comprising
2 a voltage multiplier circuit for raising voltage of a battery-powered source to a
3 raised output voltage, and wherein the means for applying electrical energy applies the raised
4 output voltage to the piezoelectric member.
- 1 21) The bicycle shock absorber of claim 19, wherein said means for applying electrical energy
2 enters a sleep mode of reduced power consumption during a detected quiescent condition of said
3 shock absorber.
- 1 22) A damper for a hydraulic system of the type having a movable displacing member
2 that acts on a fluid assembly such that movement of the displacing member creates a
3 pressure to induce flow in a passage in accordance with force on the movable displacing
4 member, wherein the damper comprises a flexible electroactive element positioned to
5 control flow in the passage and being opened by said displacing pressure and configured
6 with electrodes such that application of electrical charge to the electrodes deforms said
7 electroactive element to control said flow and regulate damping of the hydraulic system,
8 and means for sensing a disturbance and energizing said electrodes to prevent the
9 displacing member from bottoming out.
- 1 23) A damper for a hydraulic suspension of a wheeled vehicle of the type having a movable
2 displacing member that acts on a fluid assembly such that movement of the displacing member
3 creates a pressure to induce flow in a passage in accordance with force on the movable displacing
4 member, wherein the damper comprises a flexible electroactive element positioned to control the

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- 5 flow in the passage and a controller which responds to displacement to change actuating voltage
- 6 applied to the electroactive element and enhance efficiency of energy transferred to the wheels of
- 7 the vehicle while effectively damping the suspension.

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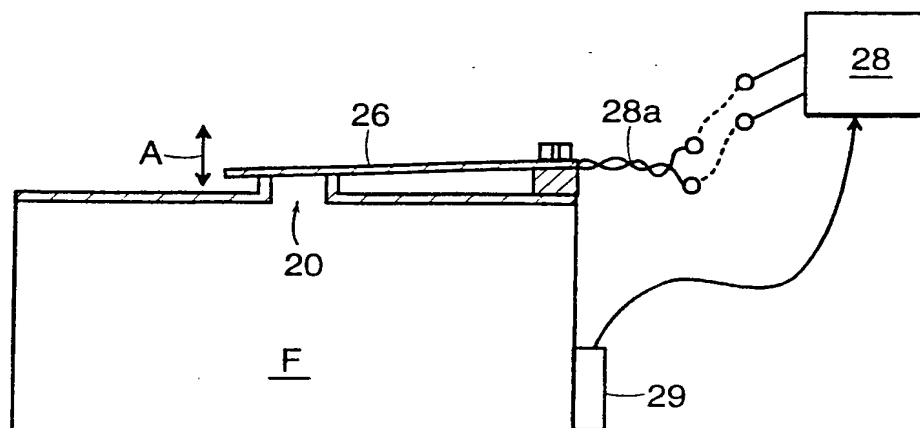


FIG. 1

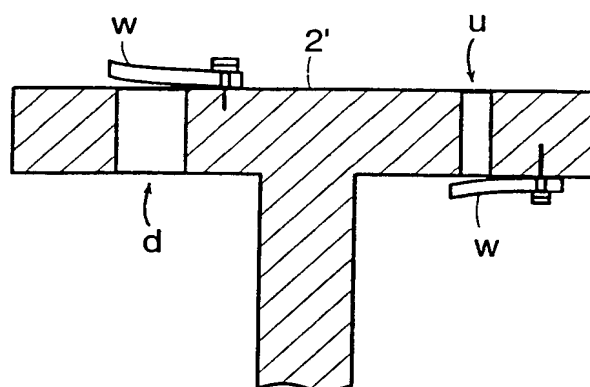


FIG. 1B

PRIOR ART

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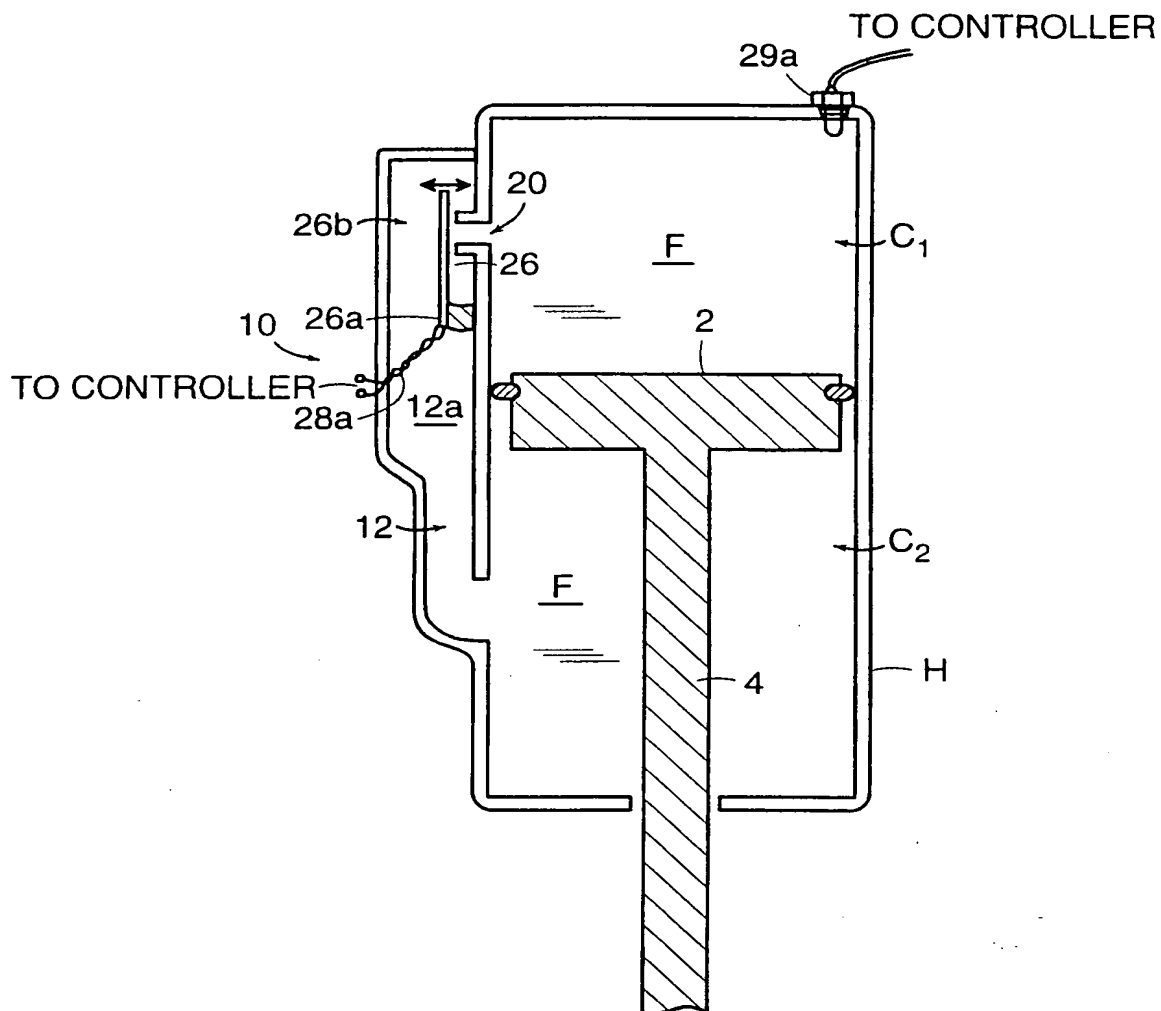


FIG. 1A

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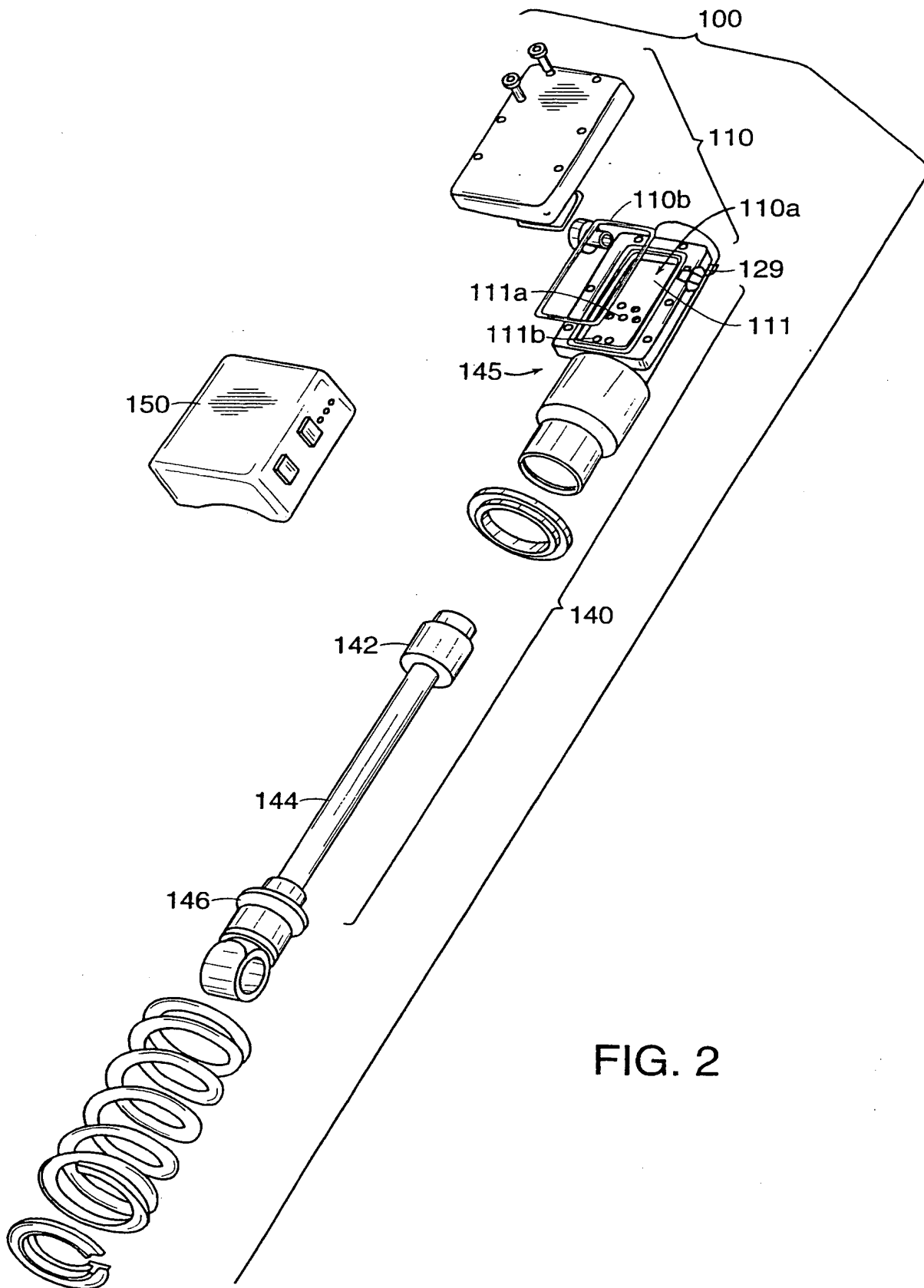


FIG. 2

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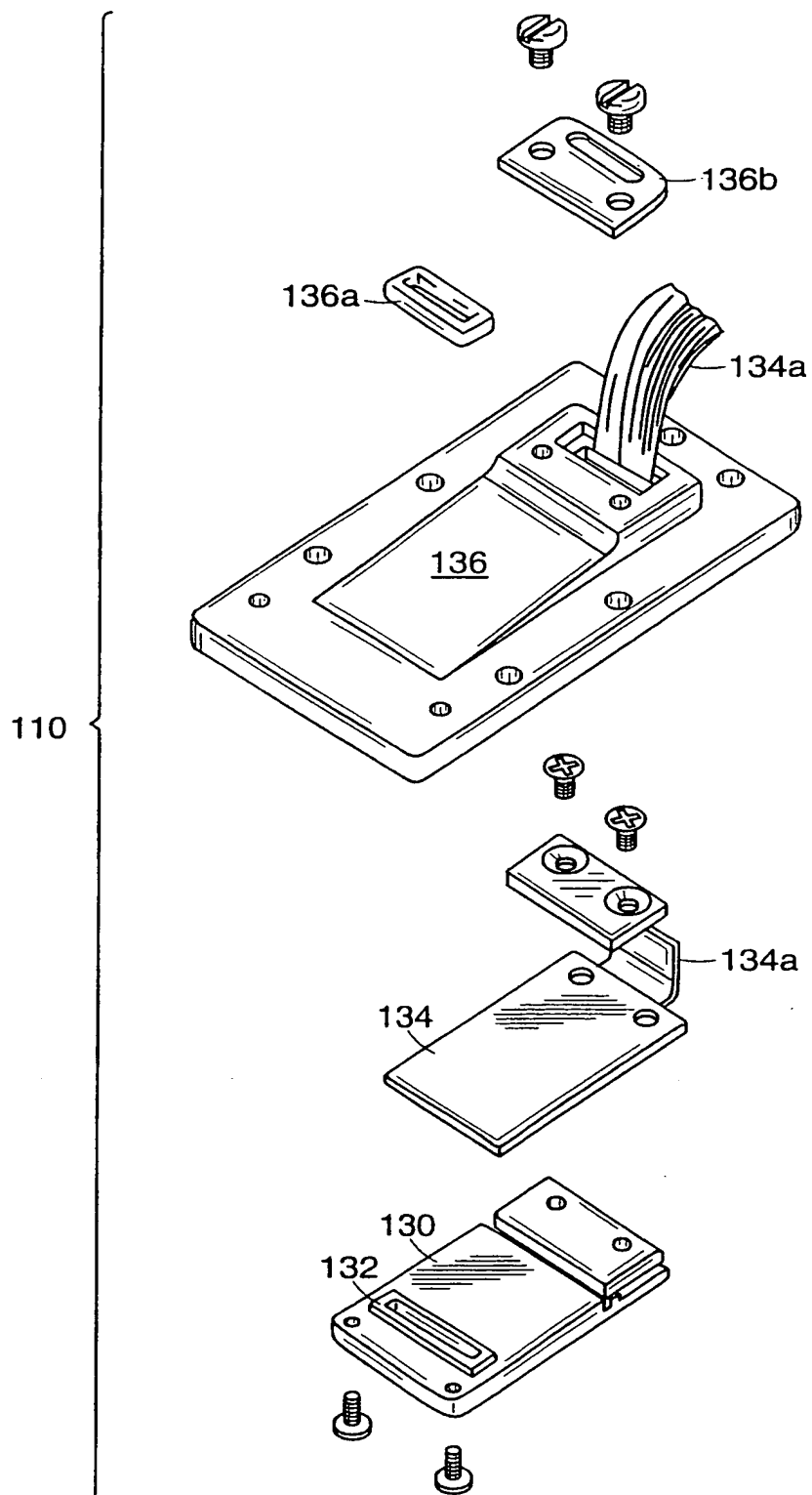


FIG. 2A

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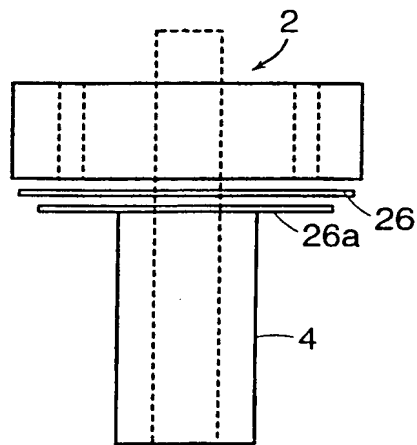


FIG. 3A

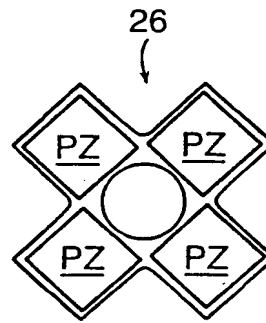


FIG. 3B

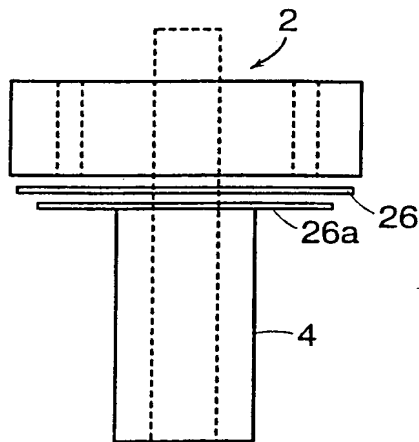


FIG. 4A

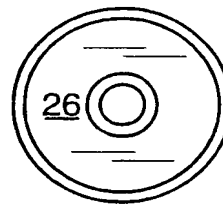


FIG. 4B

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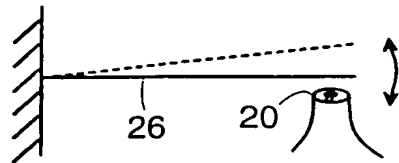
CLAMPED-FREE

FIG. 5A

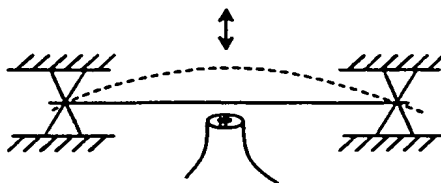
PINNED-PINNED - INITIALLY FLAT

FIG. 5B

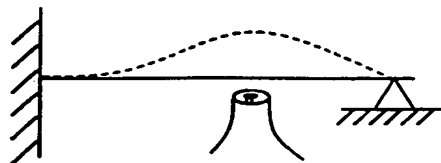
CLAMPED-PINNED

FIG. 5C

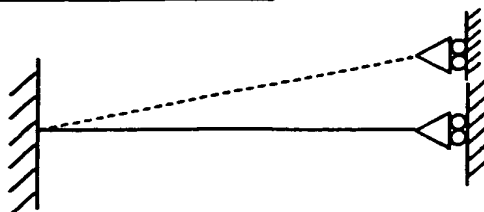
CLAMPED-SLIDING

FIG. 5D

PINNED-PINNED - INITIALLY CURVED

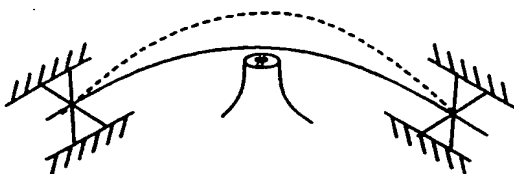


FIG. 5E

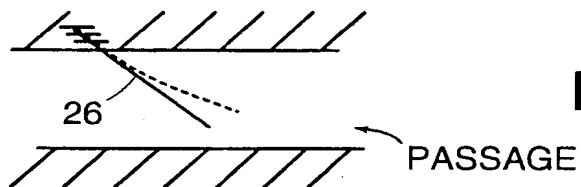


FIG. 5F

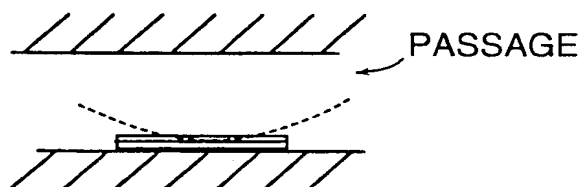


FIG. 5G

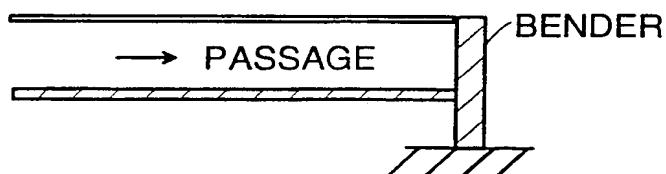


FIG. 5H

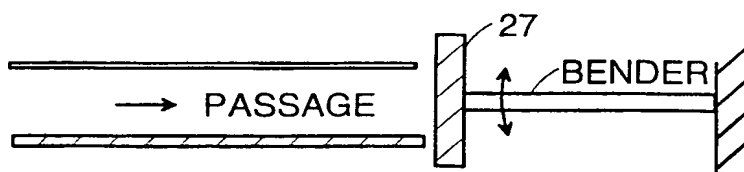
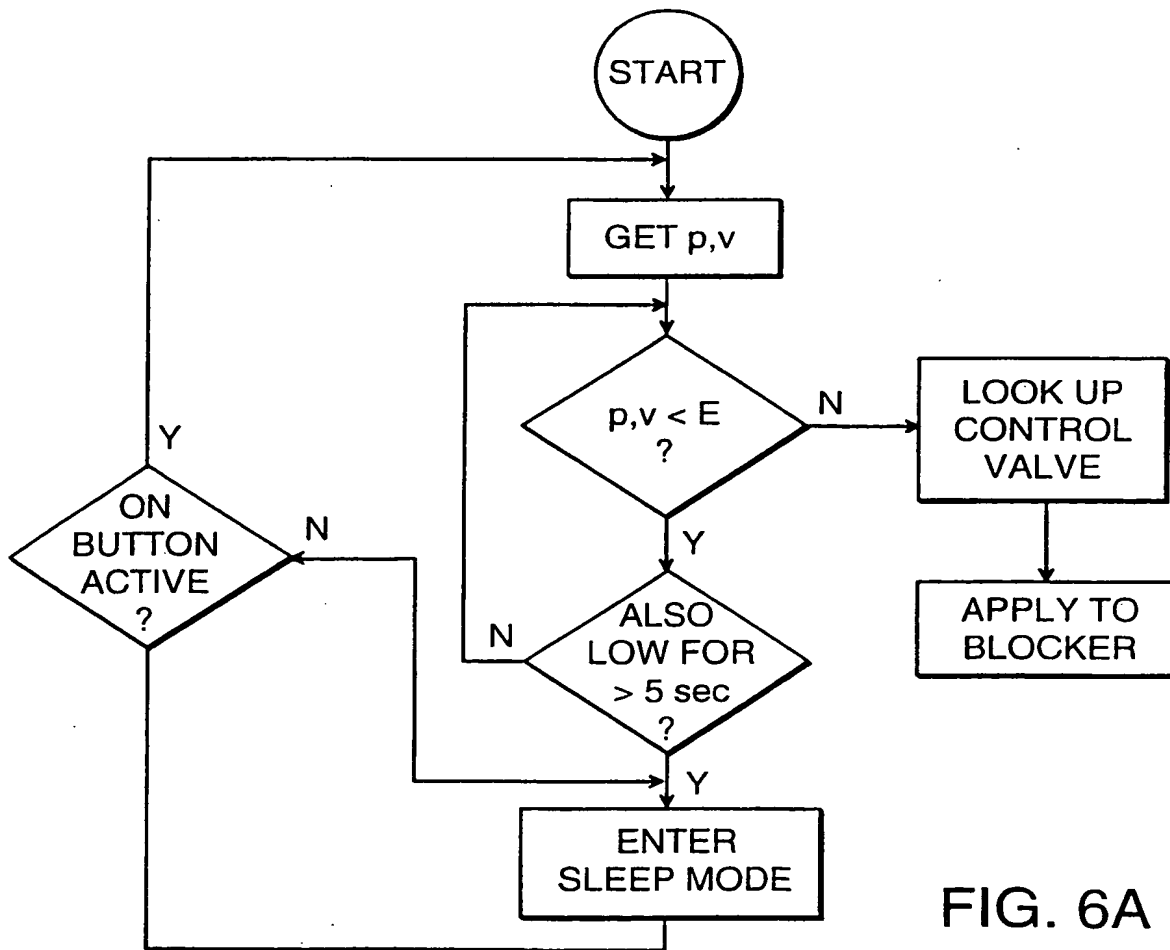
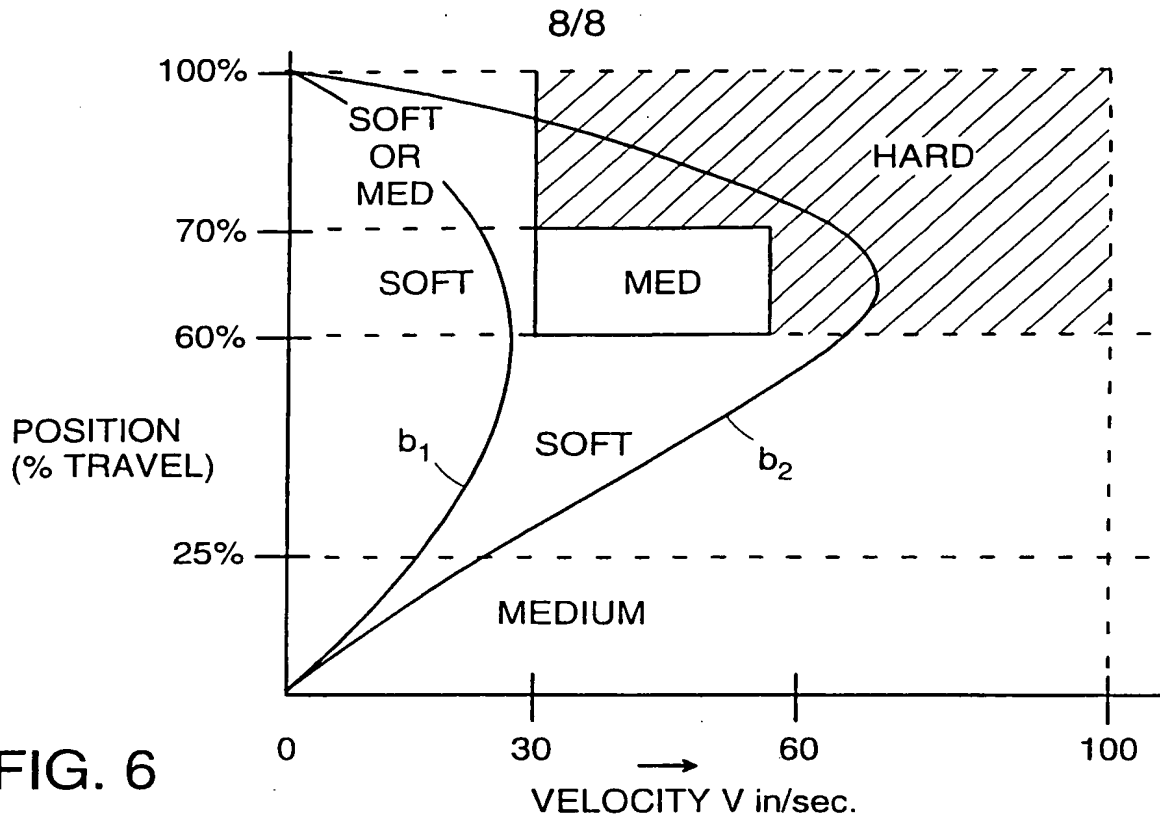


FIG. 5I



INTERNATIONAL SEARCH REPORT

Internat Application No

PCT/US 98/14374

A. CLASSIFICATION OF SUBJECT MATTER

IPC 6 F16F9/46 B60G17/08 B62K25/04

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC 6 F16F B60G B62K

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	EP 0 543 573 A (EXXON RESEARCH ENGINEERING CO) 26 May 1993	1-3, 6, 7, 9, 15-17, 19, 23
A	see column 5, line 38 - column 13, line 30; figures	4, 8, 11-14, 18, 20, 22
X	GB 2 258 904 A (ATSUGI MOTOR PARTS CO LTD) 24 February 1993	1-4, 6, 7, 9, 14-20, 23
A	see page 6, line 5 - page 30, line 12; figures	5, 8, 10-13, 21, 22
	-/-	

☒ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

* Special categories of cited documents :

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"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

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"&" document member of the same patent family

Date of the actual completion of the international search

18 November 1998

Date of mailing of the international search report

25/11/1998

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INTERNATIONAL SEARCH REPORT

International Application No

PCT/US 98/14374

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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A	---	4,5,8, 10,21,22
A	EP 0 619 210 A (FORD MOTOR CO) 12 October 1994 see the whole document	1,8,9, 14,19
P,A	WO 98 25061 A (LAZARUS KENNETH B ;MOORE JEFFREY W (US); NEWMAN JAMES (US); SAARMA) 11 June 1998 cited in the application see abstract; figures	1,8,10
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Information on patent family members

International Application No

PCT/US 98/14374

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Attorney Docket No. 202-115

Application Serial No. 101725,038